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ELECTROPRODUCTION OF PIONS

by

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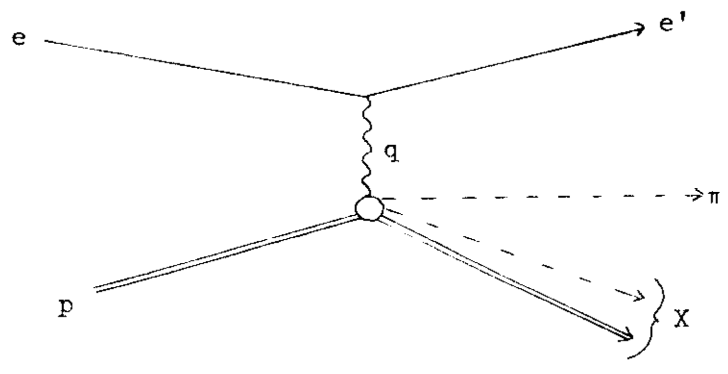
During the last years electroproduction of pions was studied in the region of the first nucleon resonance with coincidence experiments by several groups(1,2). We report a spark chamber experiment at energies of the virtual photon from 0.7 GeV up to 3 GeV, improved with respect to an earlier version(3). We measured electroproduction of single positive pions on hydrogen detecting the scattered electron and the produced pion in coincidence:

$$(1) \qquad e + p \rightarrow e' + \pi^{+} + n$$

In addition to this reaction we also detected positive and negative pions from multiple pion production:

$$(2) \qquad e + p \rightarrow e' + \pi^{\pm} + (N + \pi + \ldots)$$

These processes may be described by the following diagram:



e	$\hat{=}$	four momentum of the initial electron,
e'	$\hat{=}$	four momentum of the final electron,
q	$\hat{=}$	four momentum of the virtual photon,
π	$\hat{=}$	four momentum of the detected pion,
p	$\hat{=}$	four momentum of the initial proton,
X	$\hat{=}$	four momentum of the system of all undetected outgoing particles.

The energy component of the four momenta has the index o. The square of the total energy of the system (electron + nucleon) is given by $s = (e + p)^2$, the square of the total energy of the system (nucleon + virtual photon) by $s' = (q + p)^2$ and the square of the four momentum transfer to the recoiling nucleon system by $t = (p - X)^2$. The square of the four momentum of the virtual photon can be expressed as $q^2 = -2\, e_o\, e'_o\, (1 - \cos\theta_{ee'})$ where $\theta_{ee'}$ is the angle between the incoming and outgoing electron.

The apparatus is shown in Fig. 1. A secondary electron beam with an energy of 4.9 GeV and an intensity of 10^6 e^-/sec struck a hydrogen target 19 cm long. Behind a magnet MR, used to clear low energy background, the directions of the inelastically scattered electron and the produced pion were measured in the spark chambers SC1 and SC2. The particles were deflected in the magnet MH and their momenta were determined from the deflection angle measured in spark chambers SC1, SC2, SC3, and SC4. The detection system had a solid angle of ± 15 degrees horizontally times ± 2.3 degrees vertically which was limited by the magnet aperture. After passing through holes in spark chambers SC1 and SC2 the incoming electron beam was stopped in a tungsten absorber A inside the deflecting magnet MH. Protons and pions were separated in the threshold Cerenkov counter Č and electron identification was made by means of thick plate spark chambers SC5 and SC6. The intensity of the electron beam was measured in an ionization chamber I.CH. and was normalized against a quantameter. The spark chambers were triggered by a coincidence of the scintillation counters $T_1\ T_2\ T_3\ T_4\ T_5\ \overline{T}_6\ \overline{T}_7$ which means that at least two charged particles had to traverse the whole apparatus. After 10,000 pictures were scanned 2,000 of them were measured on digitized measuring tables and completely analyzed. Out of these we got a total number of 174 events with single pion electroproduction.

To separate the single pion production from the reaction (2) we calculated the mass m_X of the unobserved particle system. In the case of single positive pion production the mass m_X must be equal to the mass of the recoiling neutron, whereas in multiple pion production the missing mass m_X is higher than the nucleon mass by at least one pion mass. In reactions where a negative pion was detected this pion could only arise from multiple pion production. In Fig. 2 we plotted the spectra of the missing mass m_X for both positive and negative pion production in three different intervals of the virtual photon energy.

In Fig. 2a the mass of the recoiling nucleon shows up clearly. This proves that in this energy region below the ρ^0 threshold the single pion production is the dominating process. At higher energies of the virtual photon multiple pion production dominates, as can be seen in Figs. 2b and 2c. All events in Figs. 2b and 2c in the region of $0.8 < m_X < 1.05$ GeV are treated as events of single pion production because the experimental width of the mass distribution of the recoil nucleon as seen in Fig. 2a is about ± 0.1 GeV and the recoil mass distribution for negative pion production due to multiple pion production starts at about 1.1 GeV. The $\pm 10\%$ error of this treatment due to possible overlapping of the single pion peak and the multiple pion distribution is taken into account in the cross section calculation.

The distribution of the square of the four momentum of the virtual photon for the single pion production events is shown in Figs. 3a-c in the three energy intervals. The virtual photons in the observed processes are close to the mass shell. The main contribution arises at $|q^2| \leq 0.1$ GeV^2.

The cross section $\frac{d\sigma}{dt}$ for electroproduction as a function of the four momentum transfer t to the nucleon is shown in Figs. 4a-c. We got these values by integrating over the accepted region of q^2 and averaging over the interval of s' and the azimuthal angle Φ between the plane defined by the virtual photon and the pion and the plane defined by the incoming and outgoing electron. The

Φ distribution of all measured events is compatible with isotropy, as can be seen in Figs. 5a-c. The results are corrected for pion decay, bremsstrahlung of incoming and outgoing electrons and errors in particle identification. In all figures and calculations we have neglected those few events the acceptance of which was less than 1% of the mean value.

Because the q^2 values are very small it is possible to compare our data with photoproduction of positive pions. In the limit $q^2 \to 0$ the connection between electro- and photoproduction is given[4,5] by:

$$\left(\frac{d^3\sigma}{ds'\,dq^2\,dt}\right)_{\substack{\text{electro-}\\\text{production}}} = \frac{\alpha}{2\pi}\,\frac{(s'-M_p^{\,2})}{(s-M_p^{\,2})^2}\,\frac{1}{q^2}\left(1+\frac{2(s-M_p^{\,2})(s-s')}{(s'-M_p^{\,2})^2}\right)\left(\frac{d\sigma}{dt}\right)_{\substack{\text{photo-}\\\text{production}}}$$

By means of this formula we compare experimental results from photoproduction of positive pions[6,7] with our measured cross sections. We find good agreement, as can be seen in Figs. 4a-c.

Acknowledgements

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Figure Captions

Fig. 1 Experimental setup.

Figs.2a-c Spectrum of m_X for the reaction $e + p \rightarrow e' + \pi^{\pm} + X$ weighted with the acceptance Acc for 3 intervals of the energy of the virtual photon

a) $0.7 < q_o < 1.1$ GeV

b) $1.1 < q_o < 2.0$ GeV

c) $2.0 < q_o < 3.0$ GeV.

Acc is calculated by integration over the accepted region of the azimuthal angles of the electron and pion.

Figs.3a-c Number of events N as a function of q^2 weighted with the acceptance Acc for the reaction $e + p \rightarrow e' + \pi^+ + n$ in 3 intervals of the energy of the virtual photon

a) $0.7 < q_o < 1.1$ GeV

b) $1.1 < q_o < 2.0$ GeV

c) $2.0 < q_o < 3.0$ GeV.

Figs.4a-c Differential cross section $\frac{d\sigma}{dt}$ for electroproduction as a function of the four momentum transfer t to the recoil nucleon for the reaction $e + p \rightarrow e' + \pi^+ + n$ integrated over the accepted region of q^2 and averaged over the following intervals of the energy of the virtual photon

a) $0.7 < q_o < 1.1$ GeV

b) $1.1 < q_o < 2.0$ GeV

c) $2.0 < q_o < 3.0$ GeV.

Computed values for the cross section based on photo-production values are also shown.

Figs.5a-c Distribution of the azimuthal angle Φ between the plane defined by the virtual photon and the pion and the plane defined by the incoming and outgoing electron weighted with the acceptance Acc' for the reaction $e + p \rightarrow e + \pi^{+} + n$ in 3 intervals of the energy of the virtual photon

a) $0.7 < q_o < 1.1$ GeV

b) $1.1 < q_o < 2.0$ GeV

c) $2.0 < q_o < 3.0$ GeV.

Acc' is calculated by integration over the accepted region of the azimuthal angle of the electron.

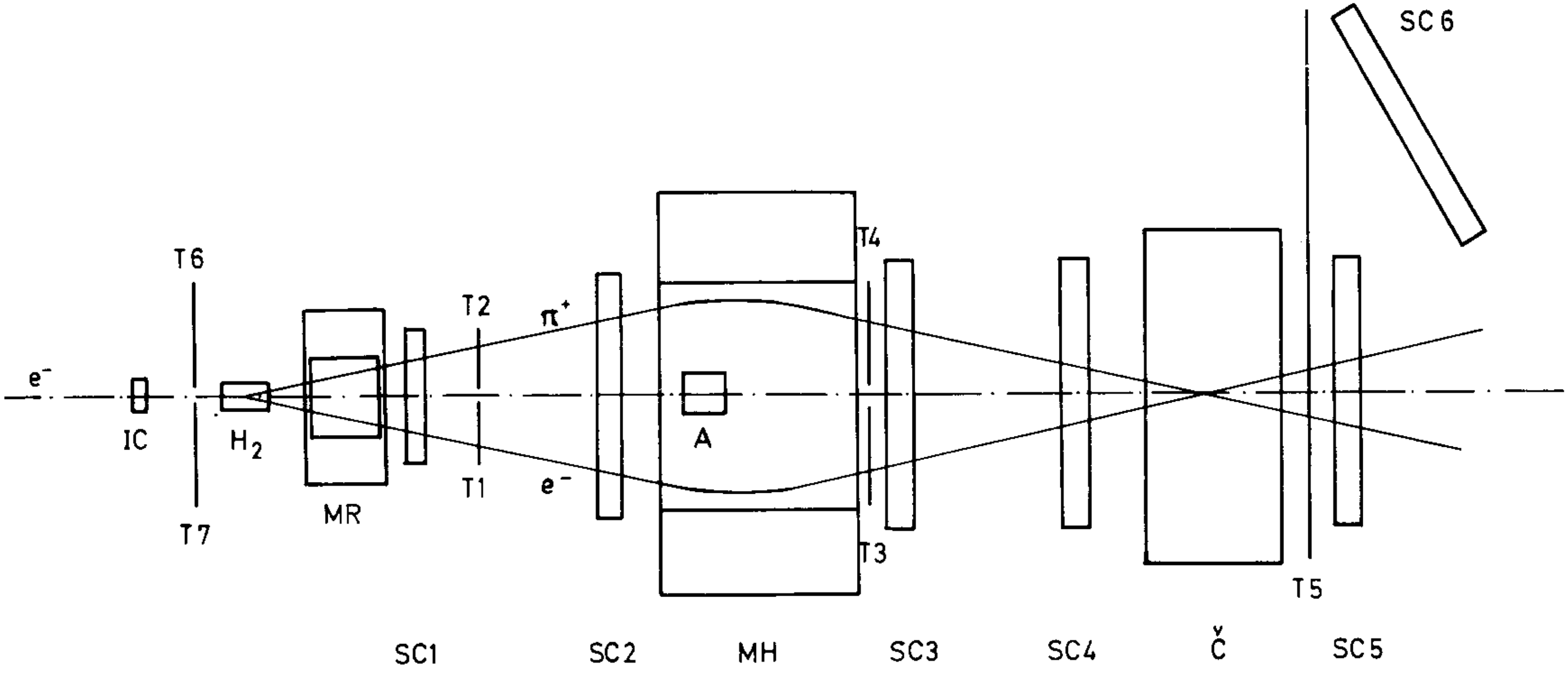


Fig.1

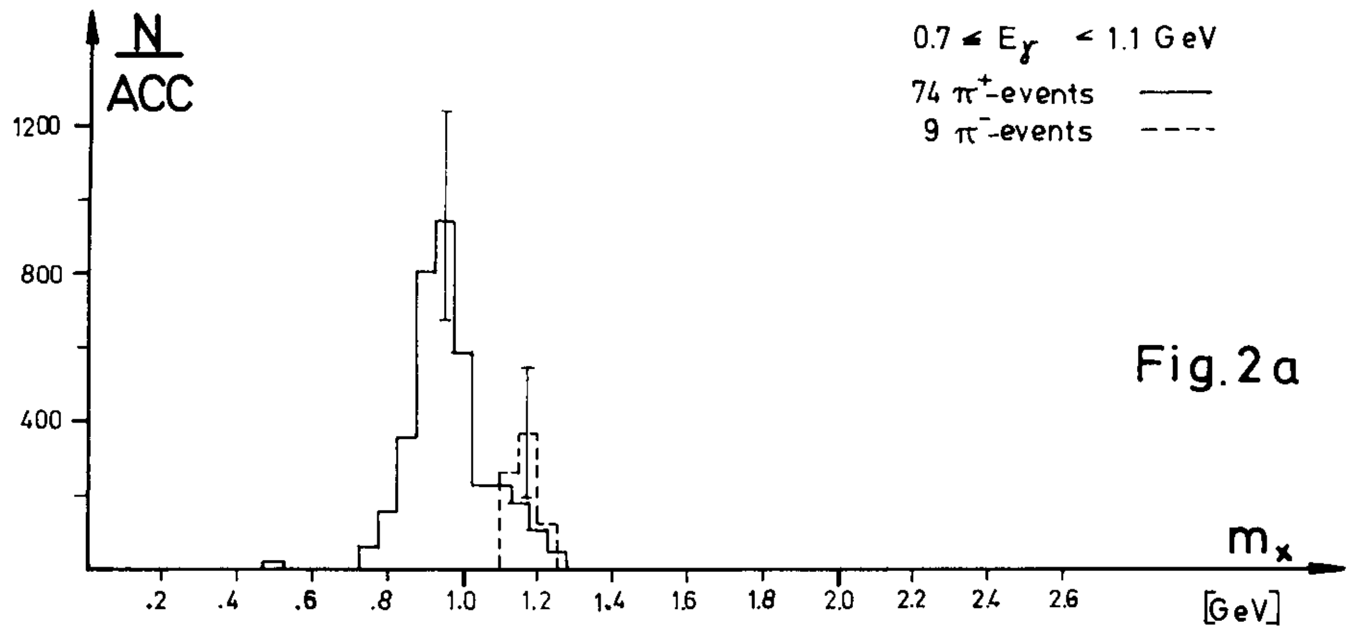


Fig. 2a

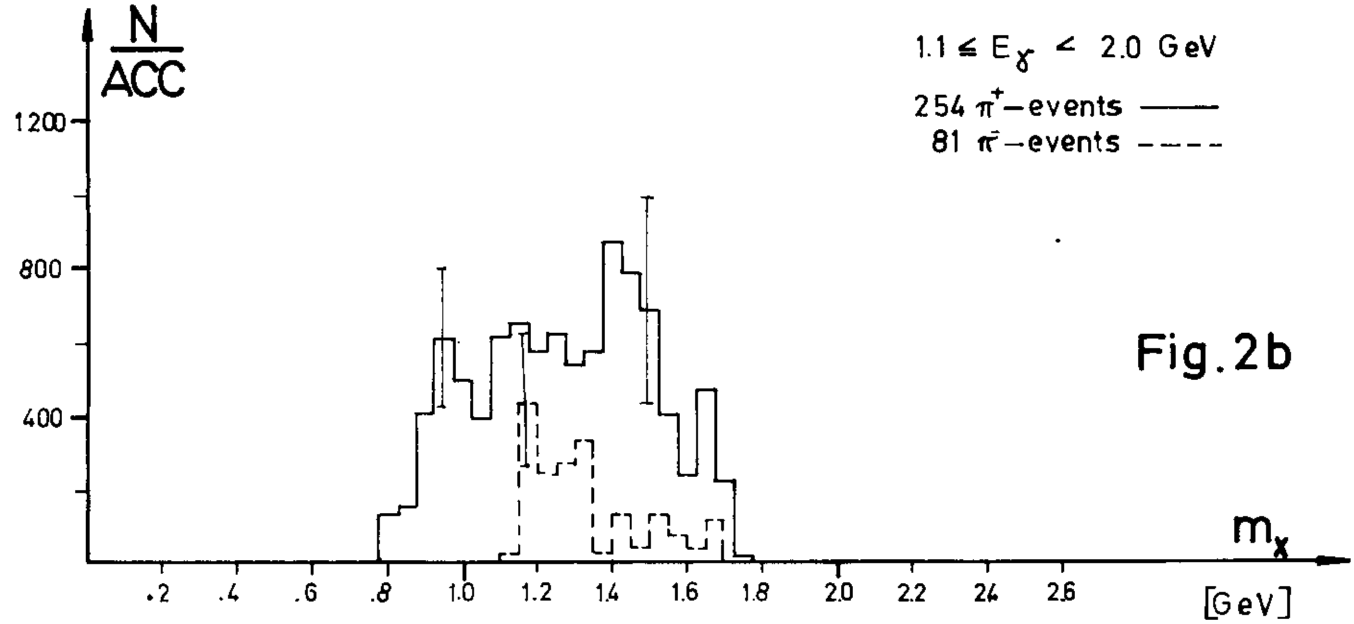


Fig. 2b

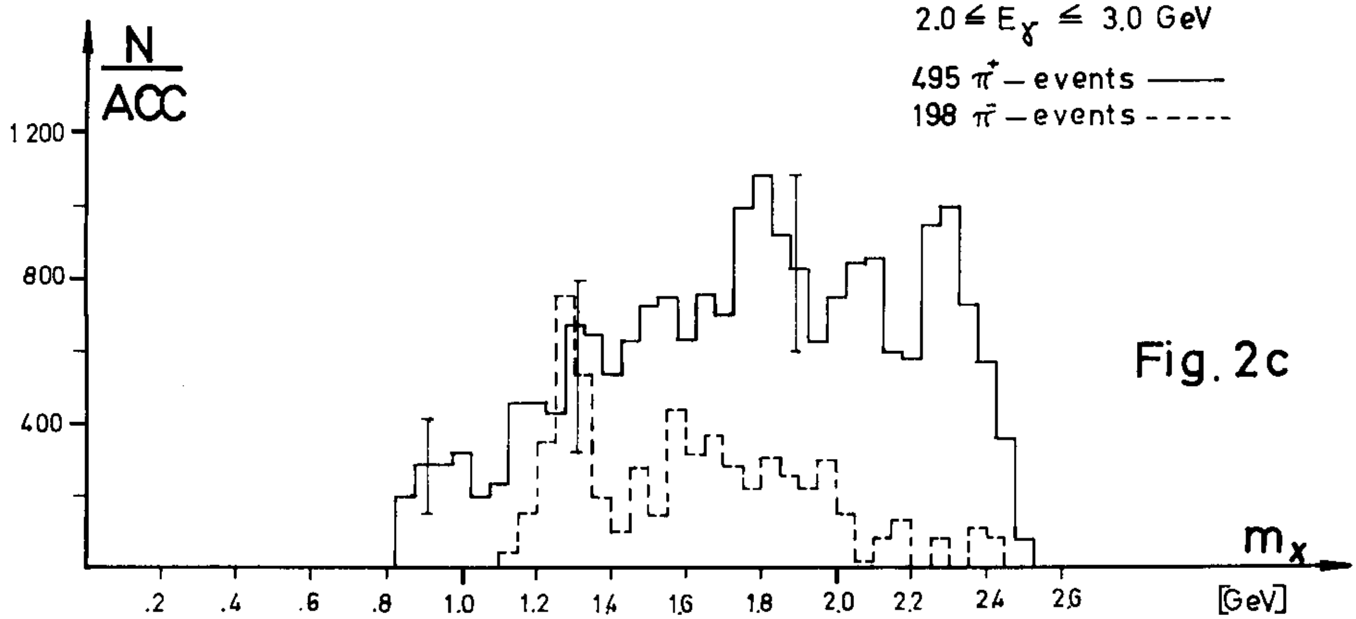
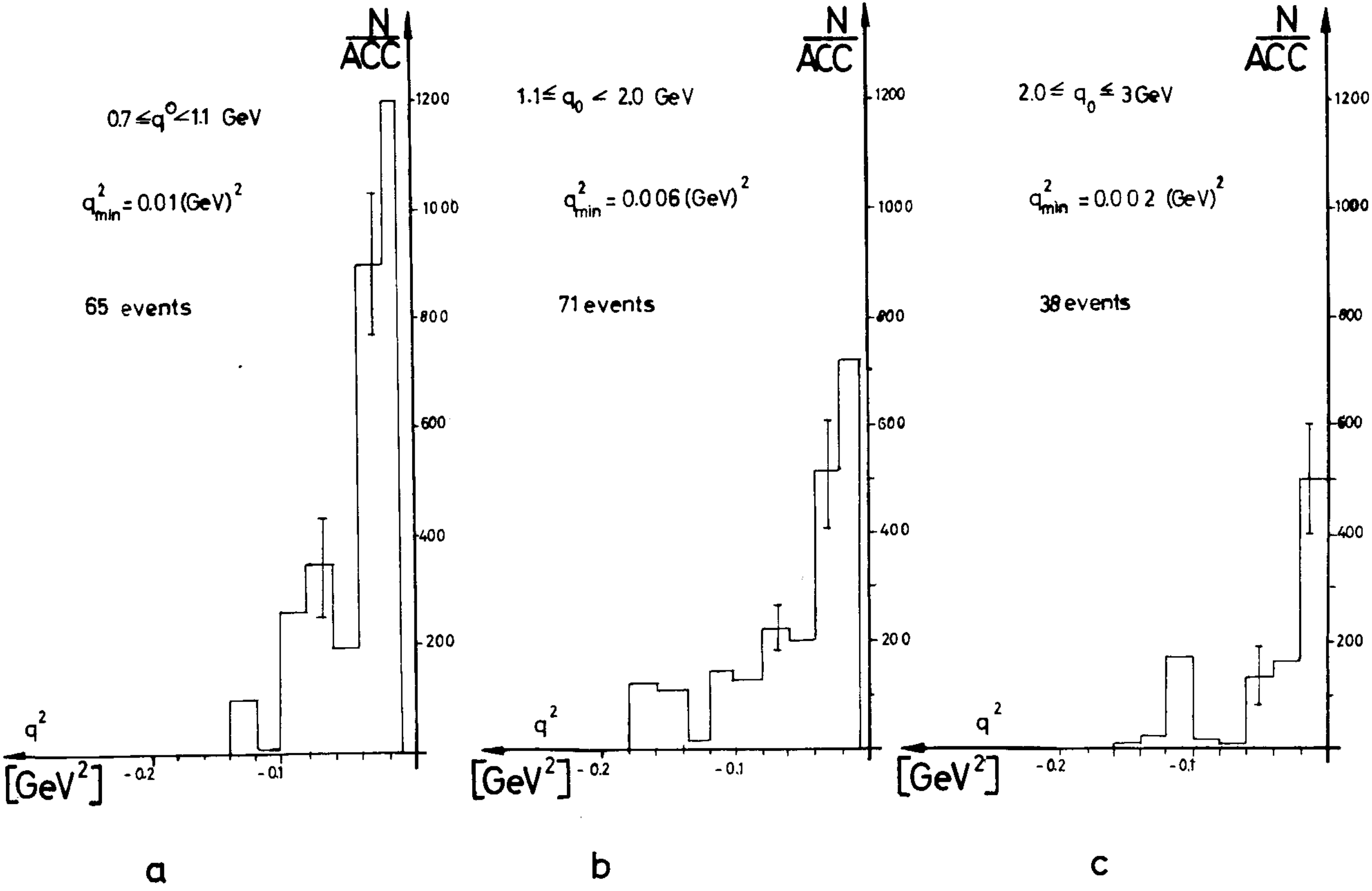


Fig. 2c



N/ACC
0.7 ≤ q⁰ < 1.1 GeV
q^2_{min} = 0.01 (GeV)²
65 events
q²
[GeV²]
-0.2
-0.1
200
400
600
800
1000
1200
a
N/ACC
1.1 ≤ q₀ < 2.0 GeV
q^2_{min} = 0.006 (GeV)²
71 events
q²
[GeV²]
-0.2
-0.1
200
400
600
800
1000
1200
b
N/ACC
2.0 ≤ q₀ ≤ 3 GeV
q^2_{min} = 0.002 (GeV)²
38 events
q²
[GeV²]
-0.2
-0.1
200
400
600
800
1000
1200
c

Fig.3

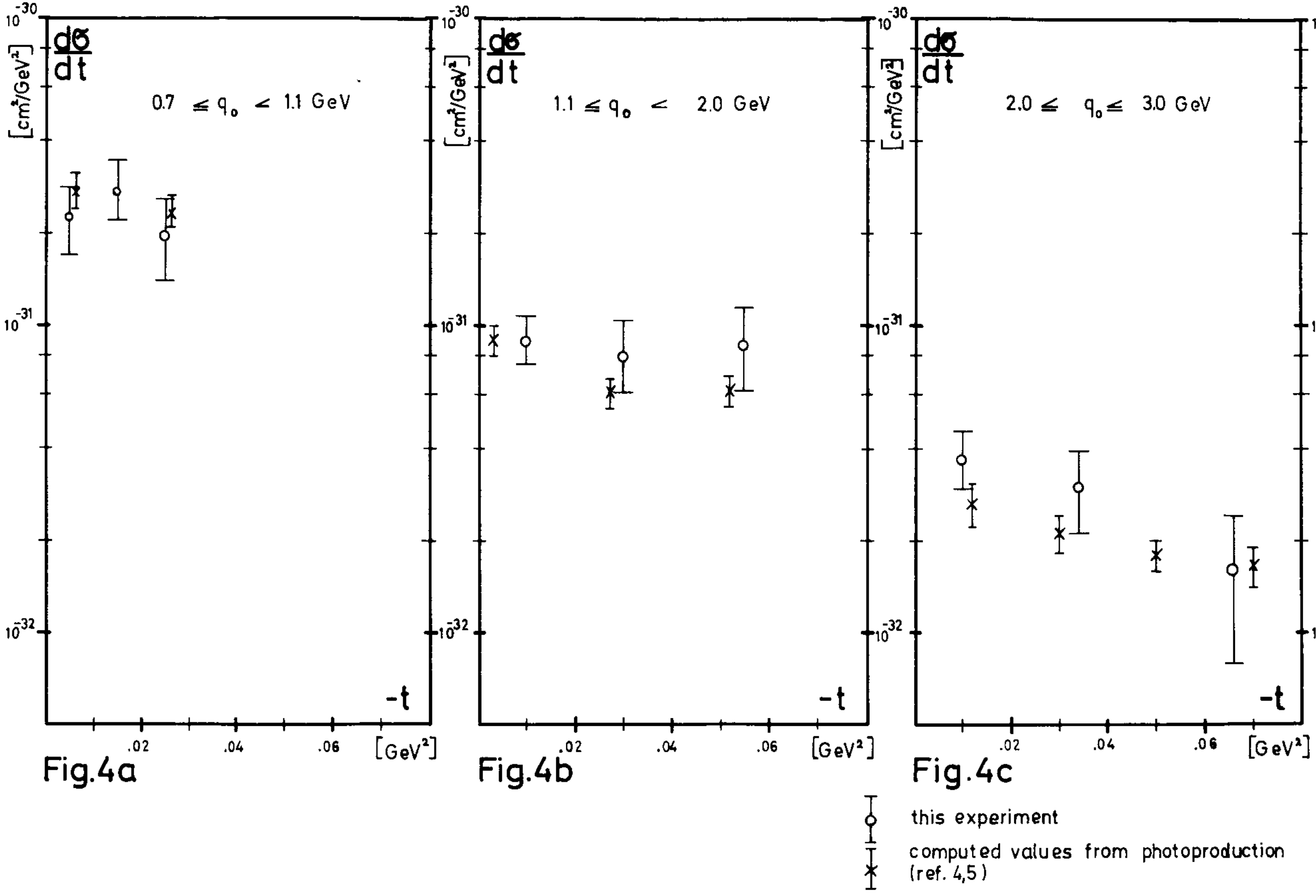
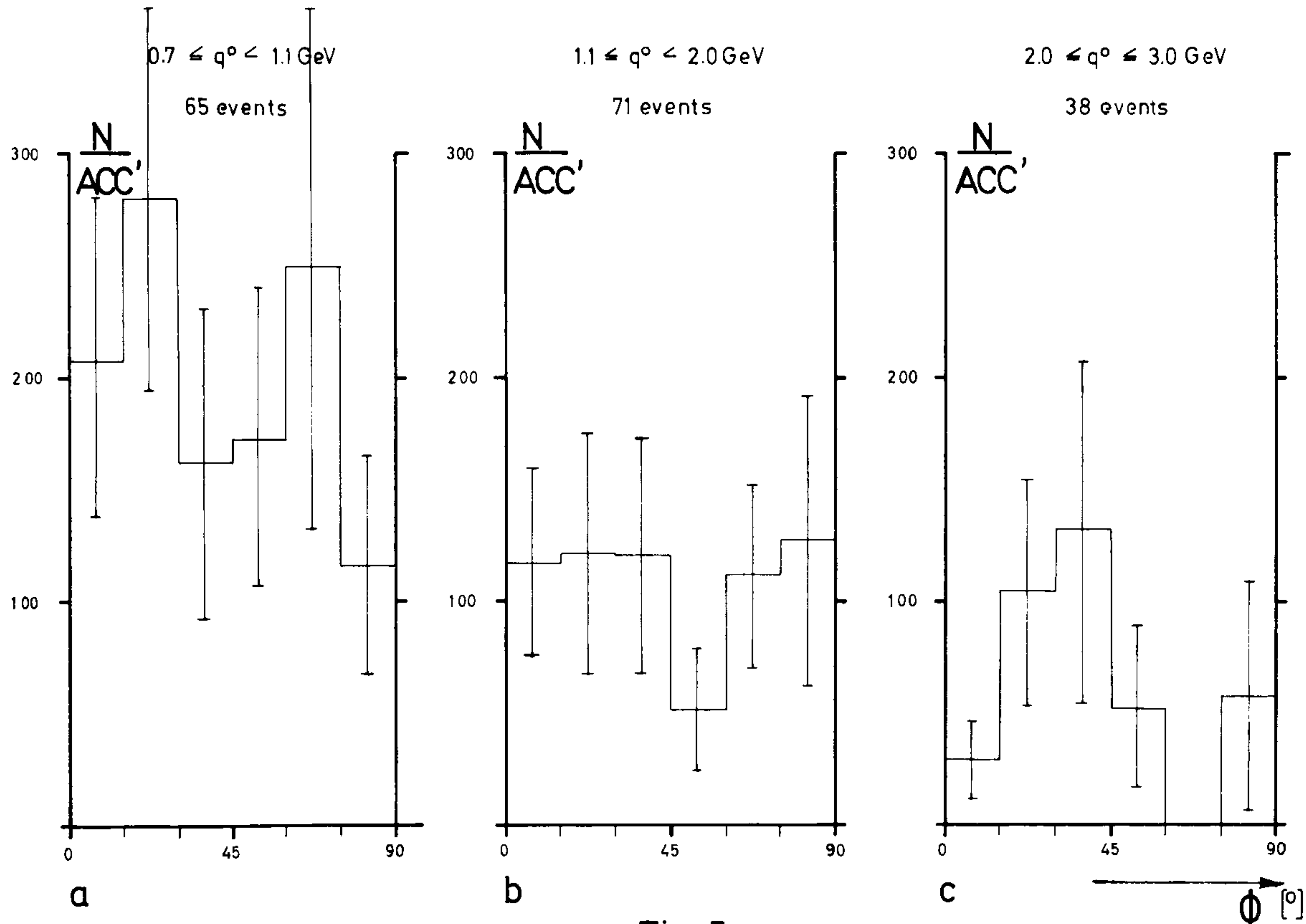


Fig.4a

Fig.4b

Fig.4c



0.7 ≤ q° < 1.1 GeV
65 events
1.1 ≤ q° < 2.0 GeV
71 events
2.0 ≤ q° ≤ 3.0 GeV
38 events
N/ACC'
300
200
100
0
45
90
a
b
c
φ [°]

Fig. 5